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Densities From Satellites OV1-15 and OV1-16

K.S.W. CHAMPION
F.A. MARCOS

OFFICE OF AEROSPACE RESEARCH
United States Air Force

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Abstract

The objectives of satellites OV1-16 (Cannon Ball I) and OV1-15 (SPADES) were to measure atmospheric density and related properties in the lower thermosphere with particular emphasis on the altitude regions 120 to 150 km. This region is where least data are available and where data are urgently required for Air Force Systems vehicles and for accurate calculations of the reentry locations of satellites. To achieve an orbit at the lowest possible altitude the mass-to-area ratio of Cannon Ball I was maximized and a spherical shape chosen to optimize the accuracy of the drag density measurements. The satellite was a 600-lb sphere with a 23-inch diameter. SPADES was a conventional OV1 vehicle. Both satellites were launched into a polar orbit on 11 July 1968. The initial perigee of Cannon Ball I was 148 km and the apogee 575 km. The initial perigee for SPADES was 158 km and the apogee 1850 km. A considerable amount of density data was obtained from orbital drag and from an onboard triaxial accelerometer on Cannon Ball I and from orbital drag, accelerometer, and ionization gauges on SPADES. The density results are being analyzed so that they can be used as the bases for considerably improved models of the lower thermosphere. With Cannon Ball I, density values were obtained below 120 km. This is a record low altitude for satellite density results and also a record low altitude for satellite instrument measurements of any atmospheric property.

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Densities From Satellites OV1-15 and OV1-16

I. INTRODUCTION

At 1130 PST on 11 July 1968 an Atlas, which put two satellites OV1-15 and OV1-16 into orbit, was launched from Vandenberg Air Force Base. These two satellites formed a coordinated program to measure atmospheric density down to 120 km altitude, plus composition, solar UV and X-ray flux, and corpuscular radiation flux. The initial orbital elements were: OV1-15, perigee 158 km, apogee 1850 km, eccentricity 0.132 and inclination 89.8° and for OV1-16, perigee 148 km, apogee 575 km, eccentricity 0.032 and inclination 89.8°. The lifetimes were 118 and 39 days respectively. Excellent data were obtained from both satellites. OV1-16 has the record for the lowest altitude (below 120 km) at which density has been measured by instruments on a satellite. This record also applies to satellite instrument measurements of any atmospheric property.

The reasons for the large-scale, low-altitude satellite density measuring program are the lack of accurate knowledge of the density profile at altitudes between 100 and 200 km and, in particular, systematic density variations in this altitude region. For example, before the density measurements with these two satellites, the dependence of density on the 10.7 cm solar flux, geomagnetic index, season, latitude, semiannual effect, and diurnal variation were not known. In fact, models such as Jacchia (1964) that did give density variations with 10.7 cm solar flux, geomagnetic index and time of day actually gave density changes opposite to

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those which now are believed to occur. In other words, the models predicted density decreases with increased solar flux and geomagnetic activity.

2. SATELLITES OV1-15 AND OV1-16

2.1 OV1-16 (Cannon Ball)

The OV1-16 satellite was a 23-inch diameter sphere which weighed 600 pounds. It was built by AFCRL. A photograph of the spacecraft is shown in Figure 1. The outside of the sphere was gold-plated and then portion of the surface was painted black. The relative black-gold areas were calculated to yield internal temperatures within the desired range. The principal experiment was a triaxial accelerometer which consisted of three uniaxial electrostatic force-rebalancing accelerometers mounted in mutually perpendicular orientations. The sphere also contained a radar beacon, batteries, appropriate logic, timing, telemetry, command and control equipment. There was no tape recorder on-board, but real time telemetry data were obtained from 199 passes over 12 stations. As there was a total of 616 revolutions, data were obtained on 32% of the revolutions.

2.2 OV1-15 (SPADES)

The OV1-15 satellite (SPADES) was a standard OV1 vehicle, consisting of a cylindrical section with multifaceted domes covered with solar cells on each end, as shown in Figure 2. The total length was 54 inches and the 27-inch diameter

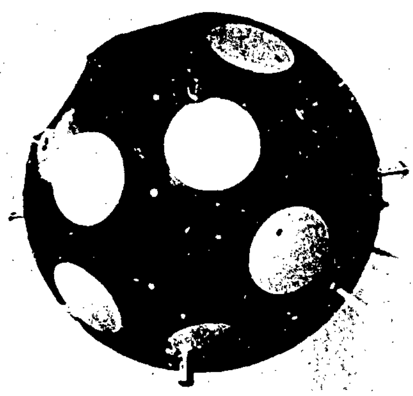

Figure 1. Photograph of the OV1-16 (Cannon Ball) Satellite, Showing Telemetry and Radar Antennas

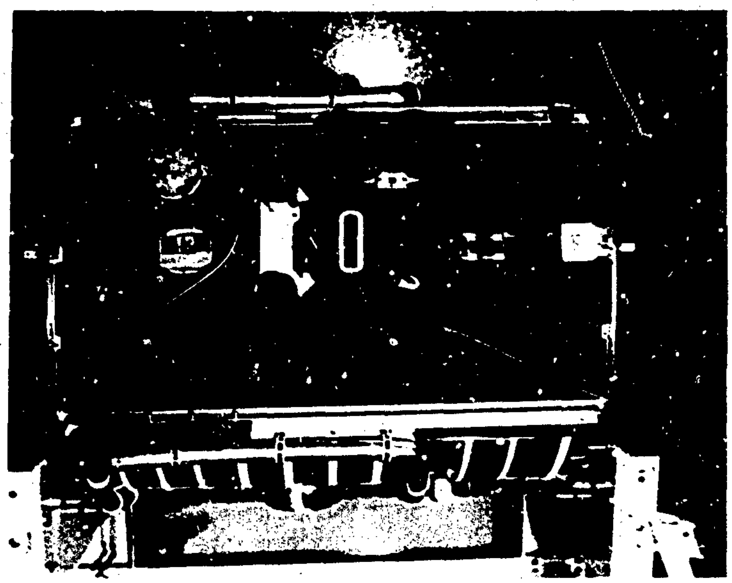

Figure 2. Photograph of the OV1-15 (SPADES) Satellite. The orifice of Ionization Gauge 1 can be seen near the center right

cylindrical section was 32 inches long. The spacecraft weighed 470 pounds. It contained eight coordinated experiments to measure atmospheric density, neutral and ion composition, solar X-ray and ultraviolet emission, ion density and temperature, and the energy and flux of precipitating charged particles. In this paper, densities measured by the onboard triaxial accelerometer system, by two ionization gauges and from orbital decay are presented and discussed. SPADES carried both ion aspect and solar eye-magnetometer aspect systems and had the capability of reorienting the spin axis using magnetic torquing.

3. DENSITY RESULTS

3.1 Ionization Gauge Results

Ionization Gauge 1 was mounted so that, as the satellite rotated, it moved in and out of ram and wake. Ionization Gauge 2 was mounted so that it was parallel to the spin axis of the vehicle. Good data were obtained from both gauges, but only results from Ionization Gauge 1 are presented in this paper. The gauges, surrounded by magnets had hot tungsten filaments, walls of ceramic and titanium, and anode and ion collectors of molybdenum.

Typical gauge data are shown in Figure 3 where gauge current is plotted as a function of angle of attack for two different altitudes. At altitudes near 150 km the ratio of current in ram to wake is 3 to 4 orders of magnitude [Champion, Marcos, and McIsaac (1969)].

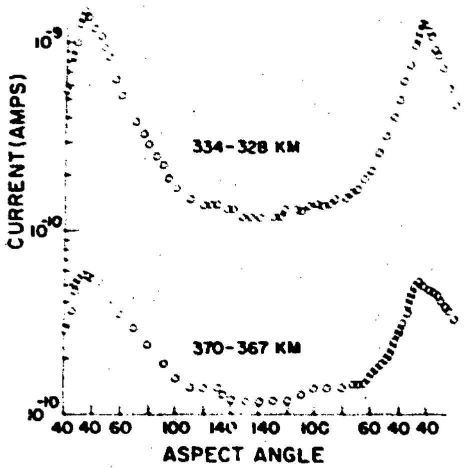

Figure 3. Gauge 1 Current as a Function of Aspect Angle at Two Different Altitudes During Revolution 1280

In Figure 4 are shown atmospheric pressure values measured during revolution 515 on 18 August 1968. These values are in good agreement with the Jacchia 1964 model if it is assumed that the gauge adsorbs all atomic oxygen incident on it when it is in the ram orientation. In practice, this adsorption will not be complete, but it will be complemented by smaller adsorbed fractions of N_2 and O_2. Results from revolutions 518 and 521 [Champion (1969)] are almost the same as for revolution 515.

Similar comments can be made about the atmospheric pressure values measured during revolutions 1280, 1282, and 1286 on 9 October 1968 and presented in Figure 5. The arrows indicate the direction of travel of the satellite. The principal data points were obtained from ram values of gauge current and are uncorrected for adsorption. The figure also shows two pressure values derived from currents when the gauge was oriented at 89°, but corrected for desorption. These values agree well with the model.

Analysis of the aerodynamic relations used to convert gauge pressure into atmospheric pressure, taking into account the geometry of the gauge entrance which was not a simple tube, shows that the values of atmospheric pressure should be increased by 20% when the ram angle is 0° and by 10% when the angle is 20°. In addition, an error in aspect angle of 20° could cause an error as large as a factor of 2 in the computed atmospheric pressure.

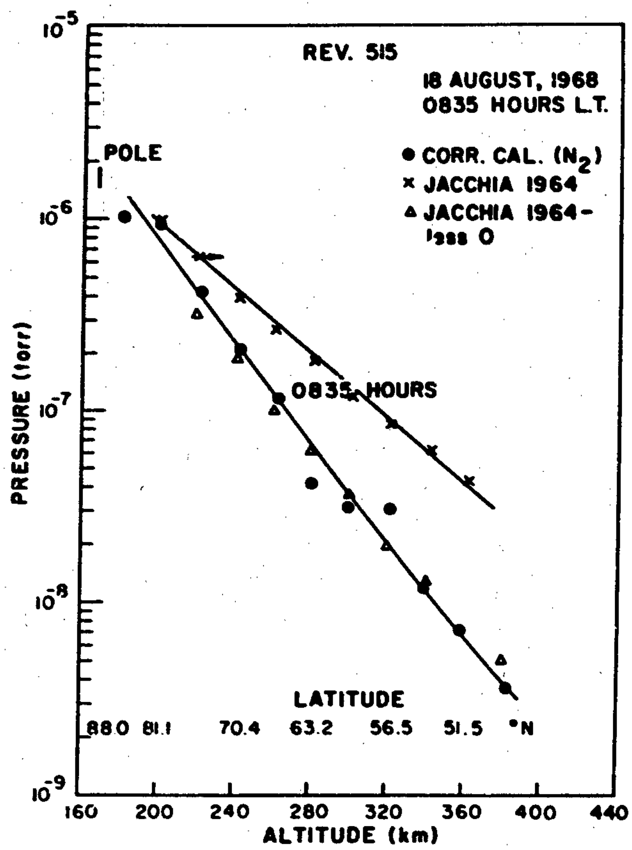

Figure 4. Atmospheric Pressure Results from Ionization Gauge 1 for Revolution 515 Compared with the Jacchia 1964 Model

3.2 Accelerometer Results

3.2.1 OV1-16

The output from one uniaxial accelerometer unit is shown schematically in Figure 6. As the satellite rotates, acceleration due to air drag modulates the accelerometer output at the spin frequency. If there is no precession of the spin axis there will also be a constant centripetal acceleration proportional to the distance of the center of the sensor from the spin axis of the vehicle. If there is precession the centripetal acceleration will be modulated at the precessional frequency. To obtain the atmospheric drag component it is necessary to separate the two accelerations.

Then the total drag

$$a_D = (a_x^2 + a_y^2 + a_z^2)^{1/2} \tag{1}$$

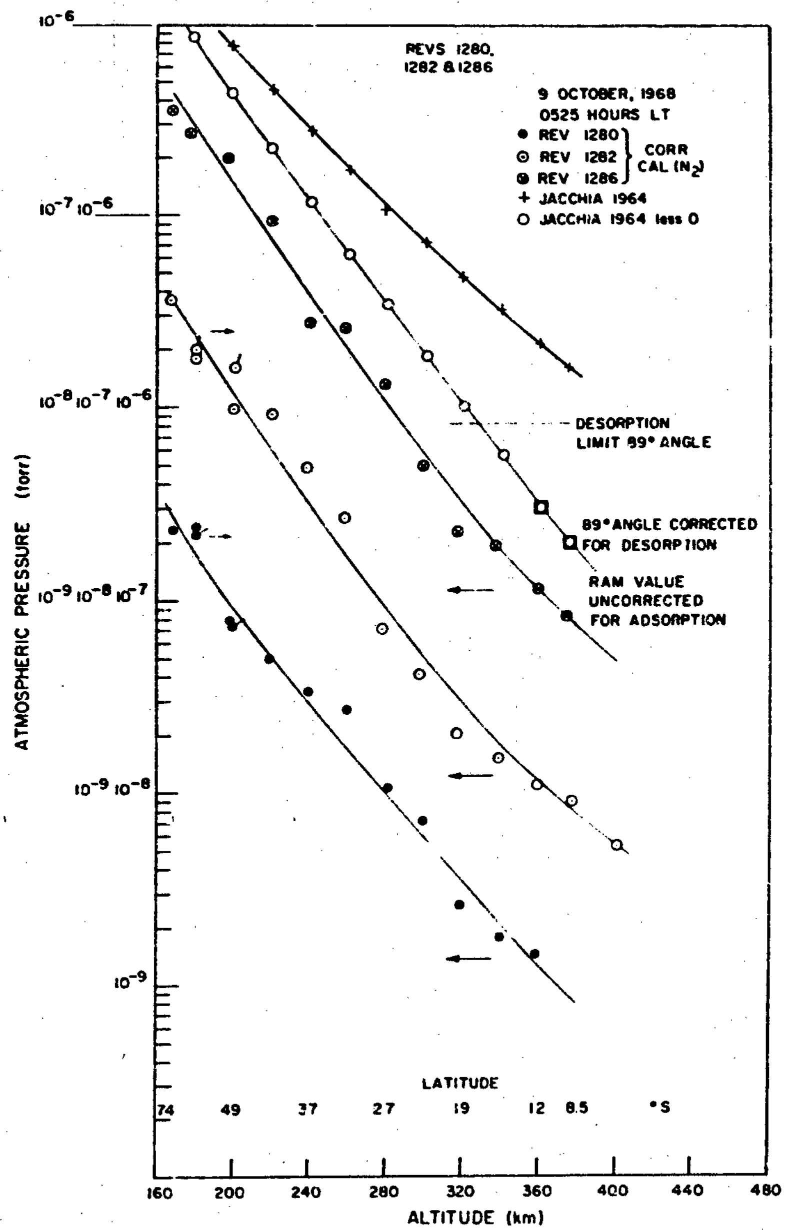

Figure 5. Atmospheric Pressure Results from Ionization Gauge 1 for Revolutions 1280, 1282, and 1286 Compared with the Jacchia 1964 Model

where

a_x, a_y, a_z are the component values at the same instant.

Figure 7 shows values of a_y obtained during a pass over Cape Kennedy. During the data acquisition period the vehicle altitude increased from 168 to 191 km. It can be seen that the modulation due to drag gradually decreased as the altitude increased [Champion, Marcos, and Schweinfurth (1969)] .

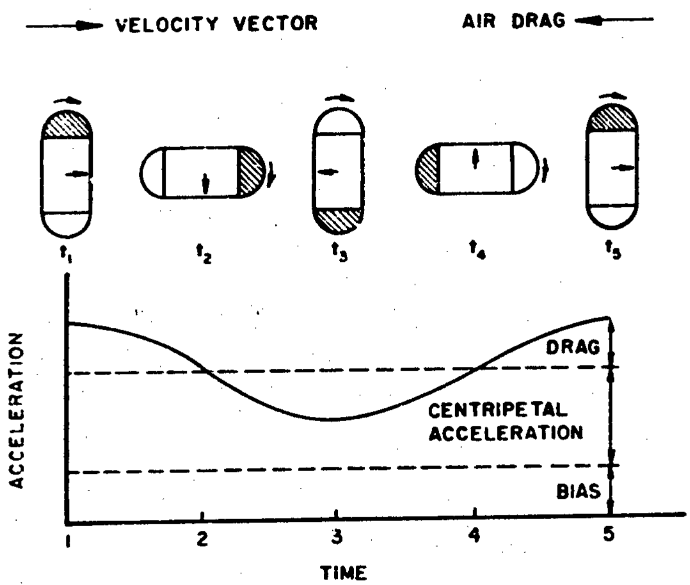

Figure 6. Idealized Output from a Uniaxial Accelerometer Unit in a Spinning Satellite with No Precession

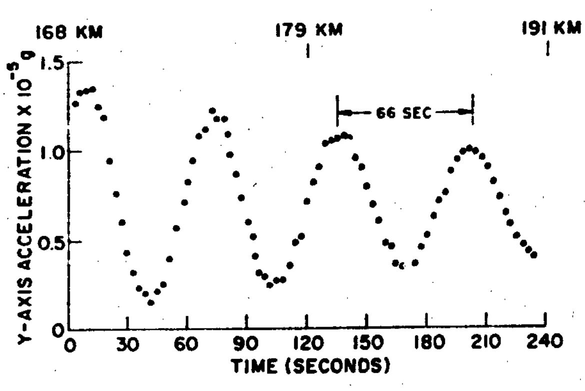

Figure 7. Accelerations Measured by the Y-axis Accelerometer on OV1-16 on 12 August 1968 During a Pass Over Cape Kennedy at Altitudes Between 168 and 191 km

Some typical density values calculated from accelerometer drag measurements using the drag equation are shown in Figure 8. The results are for revolutions 185 and 201. The perigee latitude was near 30°N. The plotted USSAS spring/fall model was for an exospheric temperature of 1300°K. The actual exospheric temperature at the time was about 1050°K and, using the USSAS summer model, results in a decrease of 10% in the density at 150 km. It can be seen that the data are in good agreement with the model.

Figure 9 shows density results obtained during passes over Thule and Fort Churchill for revolution 432. Some structure is evident in the results and agreement with the model is fair. The curvature of the density profile in the vicinity of Churchill suggests the possibility of a small density enhancement (about 12%) in the vicinity of the auroral zone. Whether this is typical or an unusual occurrence cannot be determined from this one result.

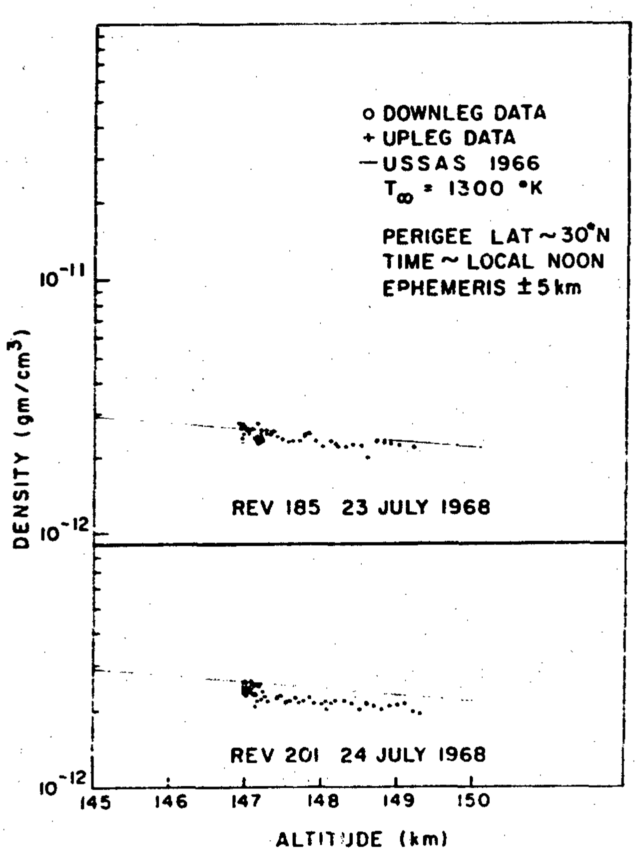

Figure 8. Accelerometer Density Data from OV1-16 at Approximately 1200 Hours Local Time on 23 and 24 July 1968 at Latitudes Near 30°N

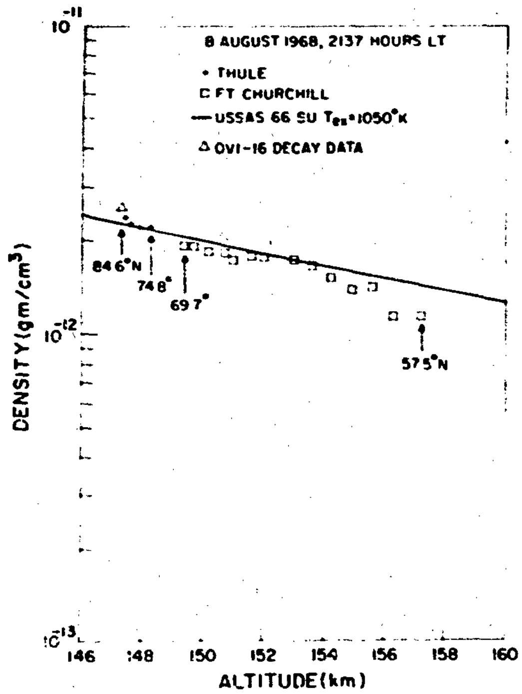

Figure 9. Density Values from OV1-16 at Approximately 2137 Hours Local Time on 8 August 1968 at Latitudes Between 57.5° and 84.6°N

It should be noted that with the close locations of Churchill and Thule a total of 7 1/2 minutes of density data were obtained from the two stations with a gap of only 16 seconds. This coverage of the auroral region and geomagnetic polar cap was extremely valuable.

Accelerometer density values obtained from OV1-16 passes over Thule and Grand Turk Island (revolution 312) and Thule and Cape Kennedy (revolution 344) are shown in Figure 10. The latitude of the satellite is given and horizontal arrows indicate its direction of motion. Also shown for revolution 312 is the perigee density calculated from orbital drag on OV1-16 and a mean curve of accelerometer density values from OV1-15 obtained at the same time and over approximately the same range of latitudes in the northern hemisphere. The experimental data are compared with the USSAS summer model with an exospheric temperature of 950°K. Most of the data agree well with the model but between 180 and 200 km the OV1-16 results are about 20% below the model values. The measurements made two days later during revolution 344 yielded results that are very similar, but there are differences in detail as can be seen in the figure.

3.2.2 OV1-15

The accelerometer units were mounted as close as possible to the center of rotation of the vehicle and aligned along its nominal spin axis. The units were

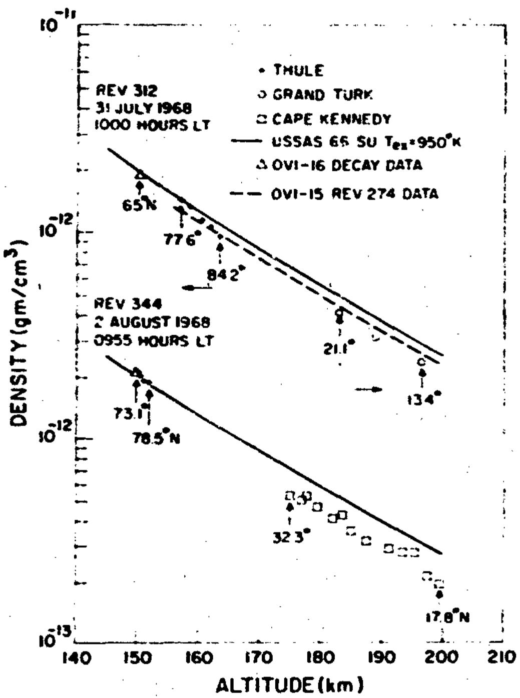

Figure 10. Density Data from OV1-15 and OV1-16 at 1000 Hours Local Time on 31 July 1968 at Latitudes Between 13.4° and 84.2°N and Data from OV1-16 on 2 August 1968 at Latitudes Between 17.8° and 78.5°N

similar to those used in OV1-16 but there were some differences in the sensitivity ranges and sampling times used.

Figure 11 shows typical acceleration data from the Y-axis accelerometer on SPADES. At high altitudes the modulation of the centripetal acceleration is due to precession of the spin axis which has a period of 23 seconds. At low altitudes a second modulation is superimposed. This is due to air drag and occurs at the spin frequency. The spin period shown in Figure 11 is 6 seconds. One way of analyzing the data is to use numerical filtering techniques to eliminate the precessional effects. The filtered data can be rapidly analyzed to determine the atmospheric drag.

Figure 12 contains orbital decay density values for OV1-15 and OV1-16, and accelerometer drag densities from OV1-15 for revolutions 21, 25, and 29 on 13 July 1968. The orbital drag and accelerometer data are in excellent agreement. The larger densities at the higher altitudes in revolution 29 follow by six hours the jump in K_p from 0^+ to 5. Seven hours later the densities are still high, but at 220 km they start to drop fourteen hours after the rise. K_p was enhanced for about twelve hours.

Density values from revolutions 33, 37, 41, and 45 on 14 July 1968 are presented in Figure 13. In addition to the accelerometer results orbital drag values for both satellites are presented. The excellent agreement between the orbital and

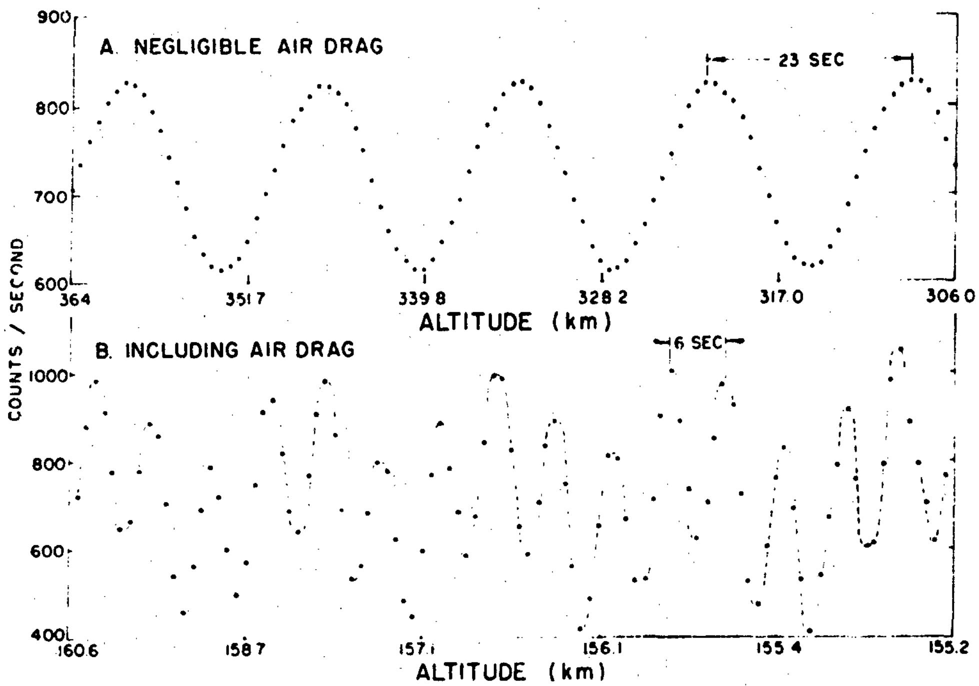

Figure 11. Accelerations Measured by the Y-axis Accelerometer on OV1-15 During Revolution 33 on 14 July 1968. A. At High Altitudes Showing Precessional Modulation of the Centripetal Acceleration and B. at Low Altitudes Showing Superimposed Air Drag Modulated at the Spin Frequency

accelerometer results can be seen. The plotted models are for an exospheric temperature of 1100°K. The calculated exospheric temperature for revolution 33 is 1170°K and for the later revolutions approximately 1110°K. It can be seen that, at 220 km altitude, the experimental densities are significantly lower than the model values.

The appreciable differences between upleg and downleg densities for revolutions 41 and 45 could be due to aspect or ephemeris errors and need to be rechecked before assigning them to atmospheric phenomena. However, the results could indicate a gravity wave initiated at the northern auroral region (latitude 75°N at the longitude appropriate to the satellite position, 229°W) at the sharp onset of the magnetic storm on 13 July 1968 when the three-hourly value of K_p jumped from 0^+, for the time interval 12 to 15 hours, to 5 for the next time interval. The foregoing point of origin assumes that the wave propagates in the north-south direction as proposed by Newton, Pelz and Volland (1969). The wave is first detected during revolution 41 and the peak disturbance arrives 34 hours after the onset of

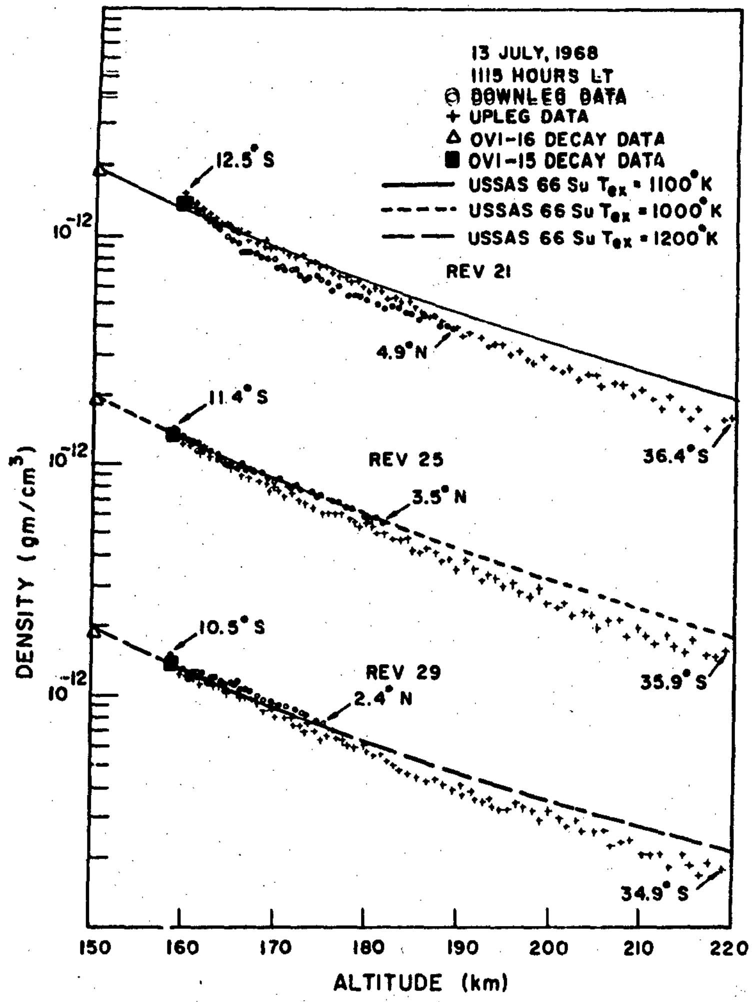

Figure 12. Orbital Drag Densities from OV1-15 and OV1-16 and Accelerometer Drag Densities from OV1-15 for Revolutions 21, 25, and 29 on 13 July 1968

the magnetic storm, during the recorded portion of revolution 45 at latitude 4°N. This corresponds to an average velocity of 65 m/sec, which is comparable with the velocities expected for gravity waves.

Drag density results from OV1-15 for revolutions 268, 271, and 274 on 31 July 1968 are shown in Figure 14. The density data in these two figures range from 10% above to 20% below the model values. (NOTE: As a result of filter response function calibration, the density values for revolutions 21, 25, and 29 and 268, 271, and 274 should be reduced by about 3%.)

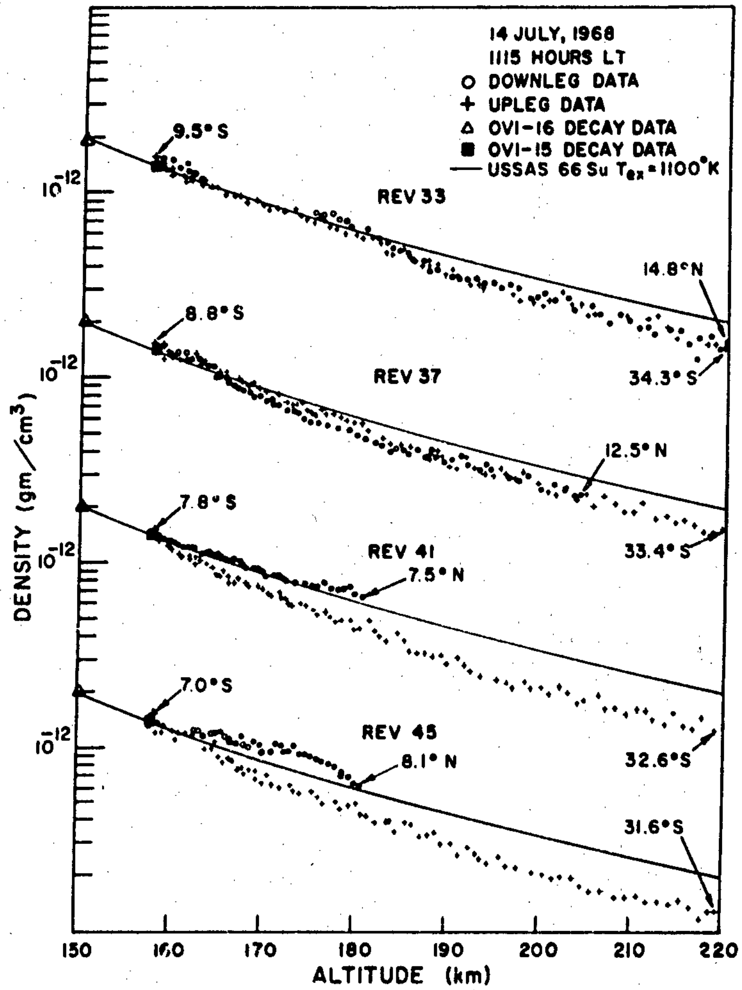

Figure 13. Accelerometer Density Data from OV1-15 at 1115 Hours Local Time on 14 July 1968, Orbital Drag Density Values from OV1-15 and OV1-16, and USSAS 1966 Summer Model

Figure 15 illustrates what can be done to mass produce data output. It is a reproduction of a computer printout of completely automatically reduced data for revolution 259 on 30 July 1968. The excellent agreement between upleg and downleg data can be seen.

3.3 Orbital Decay Density Results

Orbital drag density values have been obtained for both satellites using actual tracking data. Orbital perturbations due to drag have been computed using a very

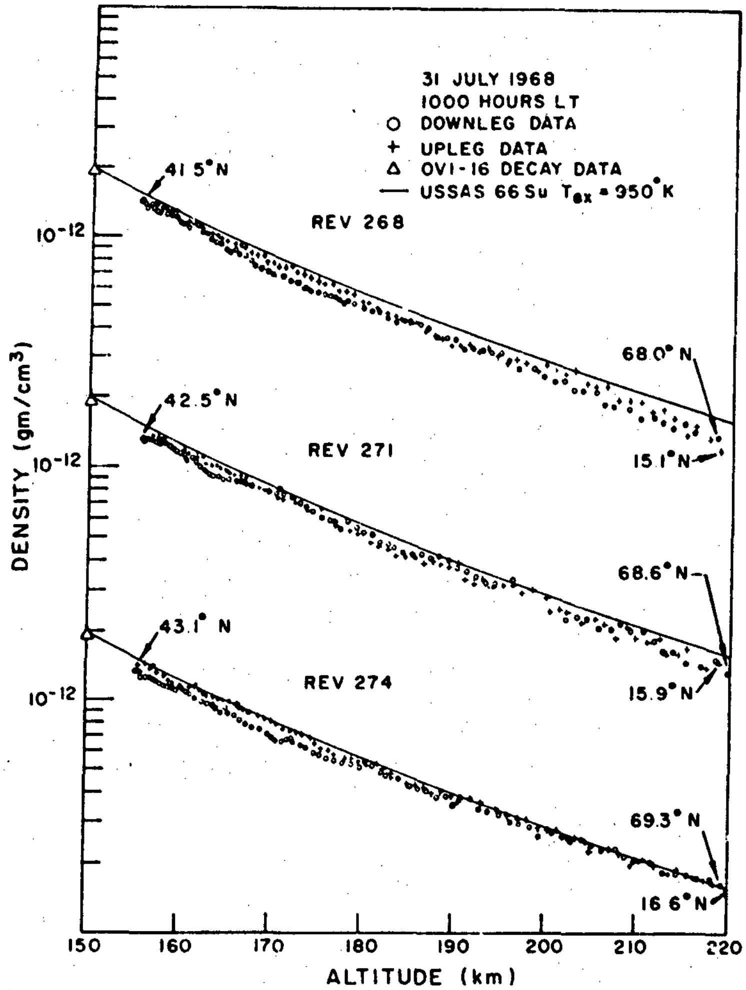

Figure 14. Orbital Drag Densities from OV1-16 and Accelerometer Drag Densities from OV1-15 for Revolutions 268, 271, and 274 on 31 July 1968

precise double precision numerical integration program. The basic part of the program is of the predictor-corrector type and operates with 3 position coordinates, 3 velocity coordinates and 1 drag quantity as a function of time. Computations were made for fit-spans of 8 to 12 revolutions. Drag density values for individual perigee passes were obtained by employing the technique of sliding fit-spans.

A large block of density data from OV1-16 is shown in Figure 16. The data are for the period 1 to 18 August 1968. The vehicle re-entered on 19 August. Also shown in the figure are perigee latitude and altitude, K_p, and $F_{10.7}$ values. It can be seen that the short term density fluctuations correlate moderately well

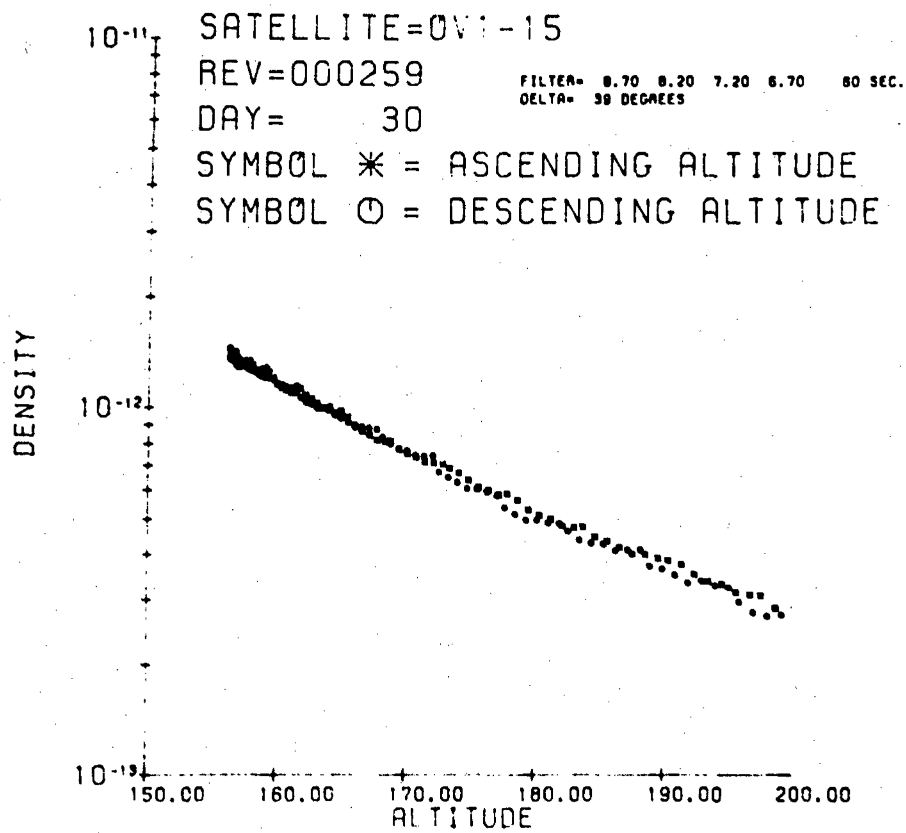

Figure 15. Computer Printout of OV1-15 Density Results for Revolution 259 on 30 July 1968

with the K_p values. From a long term point of view it can be seen that near 1 August the average density values are about 14% below the spring/fall USSAS model and agree well with the summer model. Later the densities rise (primarily due to increase in K_p) and at some times (such as 9 August) the average values agree with the spring/fall model. From 15 to 17 August the densities average about 16% above the spring/fall model, but at this time $F_{10.7}$ had increased to 180 and K_p ranged between 3 and 6. It must also be remembered that during the period 1 to 18 August the perigee altitude steadily decreased from 149 to 125 km and so it is possible that some of the long term density changes are due to model errors which vary with altitude.

Figure 17 is a reproduction of a computer printout. It includes plots of the ratio of the observed densities to those of the Jacchia (1969) model and values of K_p and $F_{10.7}$ for the period 1 to 18 August 1968. The good agreement between experiment and model, despite wide variations in K_p, $F_{10.7}$ and altitude is apparent.

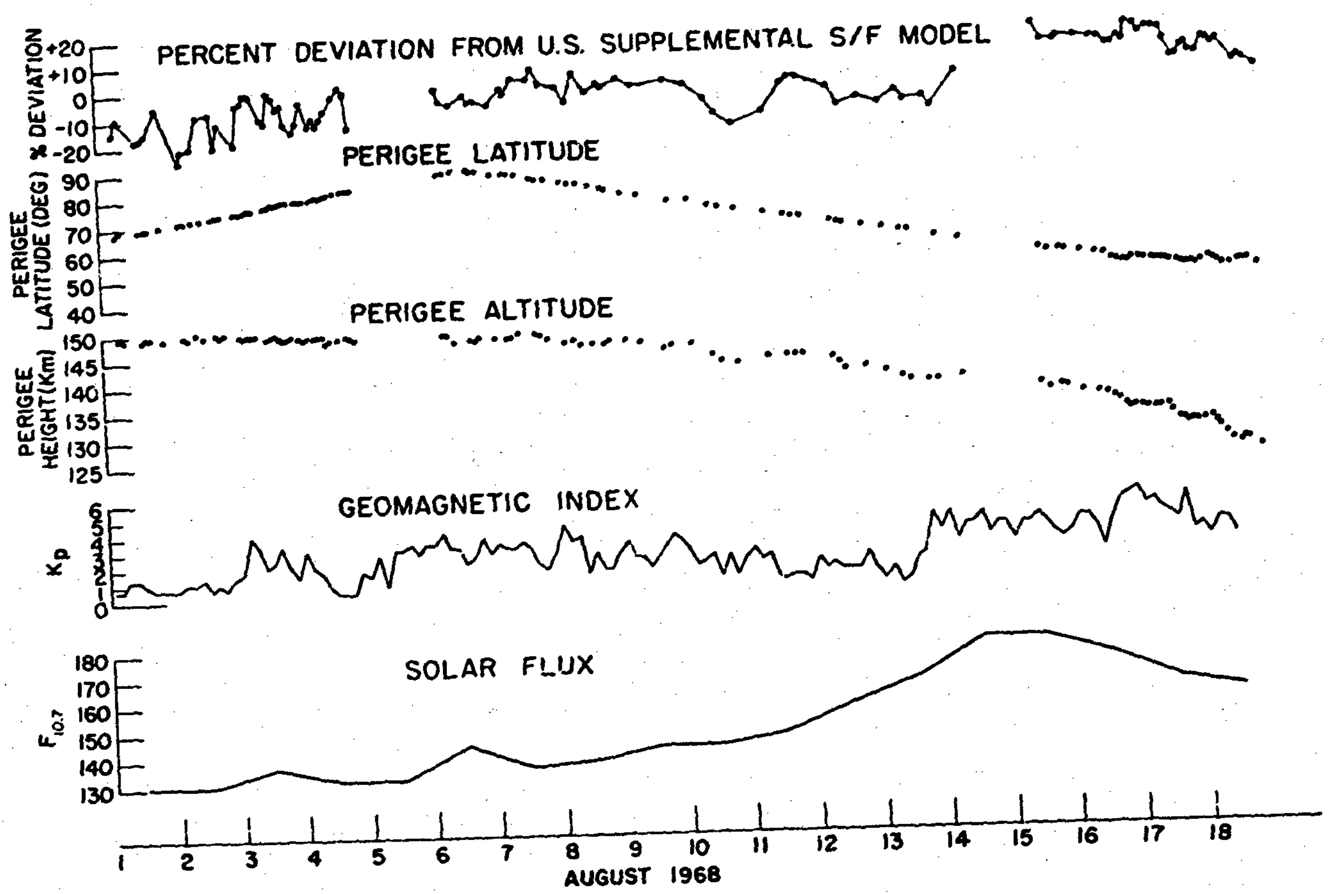

Figure 16. Orbital Drag Density Deviations from USSAS 66 Spring/Fall Model for OV1-16, Perigee Latitude, Altitude, K_p and $F_{10.7}$ for the Period 1 to 18 August 1968

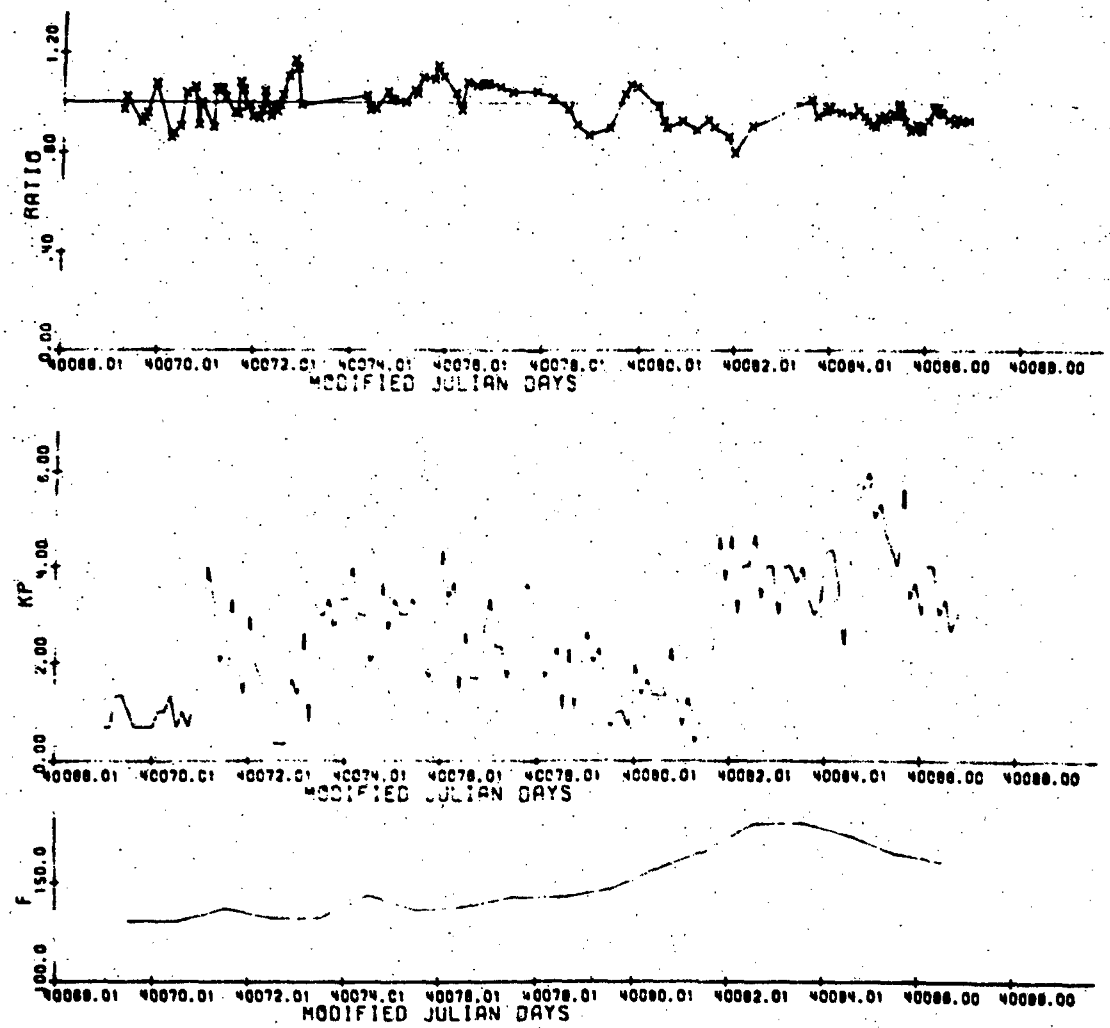

Figure 17. OV1-16 Orbital Drag Density Values Relative to the Jacchia 1969 Model for 1 to 15 August 1968, and Values of K_p and $F_{10.7}$ Solar Flux

4. CONCLUSIONS

A great deal of density data has been obtained from satellites OV1-15 and OV1-16. The results constitute the only satellite instrument measurements in existence for altitudes below 200 km. The only other instrument density data available are meager results from a few rocket flights.

Results obtained to date have shown that in the altitude region below 200 km the density does increase with increased solar flux and geomagnetic activity. Also, density values near 150 km are generally in good agreement with model values, while data at higher altitudes are lower indicating smaller scale heights than predicted by models. The data also show that the atmosphere is not static since there are irregular meteorological fluctuations in the density profiles. Finally, most of the ion gauge, accelerometer and orbital decay results are in reasonable agreement, in contrast with the consistent factor of two discrepancy between gauge and orbital decay results found by NASA scientists in Explorer 17 results.

Preliminary improved models have already been developed based on some of the results from these two satellites. It is expected that final versions of these models will have considerable use by Air Force Systems Command and other DOD users.

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13. ABSTRACT

The objectives of satellites OV1-16 (Cannon Ball I) and OV1-15 (SPADES) were to measure atmospheric density and related properties in the lower thermosphere with particular emphasis on the altitude region 120 to 150 km. This region is where least data are available and where data are urgently required for Air Force Systems vehicles and for accurate calculations of the re-entry locations of satellites. To achieve an orbit at the lowest possible altitude the mass-to-area ratio of Cannon Ball I was maximized and a spherical shape chosen to optimize the accuracy of the drag density measurements. The satellite was a 600 lb sphere with a 23-inch diameter. SPADES was a conventional OV1 vehicle. Both satellites were launched into a polar orbit on 11 July 1968. The initial perigee of Cannon Ball I was 148 km and the apogee 575 km. The initial perigee for SPADES was 158 km and the apogee 1850 km. A considerable amount of density data was obtained from orbital drag and from an onboard triaxial accelerometer on Cannon Ball I and from orbital drag, accelerometer, and ionization gauges on SPADES. The density results are being analyzed so that they can be used as the bases for considerably improved models of the lower thermosphere. With Cannon Ball I, density values were obtained below 120 km. This is a record low altitude for satellite density results and also a record low altitude for satellite instrument measurements of any atmospheric property.

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